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MECHANICAL HARVESTING OF SEA BUCKTHORN, SASKATOONS AND CHOKE CHERRIES

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Final Report

Mechanical Harvesting Of Sea Buckthorn, Saskatoons and Chokecherries

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Saskatchewan Agriculture, Food and Rural Revitalization

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1. Abstract

One of the viable alternatives to foods traditionally grown on the Canadian Prairies is small fruit or berries. The most popular berries are saskatoons, sea buckthorn and chokecherries, which are typically grown in small orchard settings. The viability of growing berries in a small orchard depends on a simple, inexpensive means of harvesting. This paper presents the development of a hydraulically powered small orchard harvester and collection system, based on individual branch shaking technology. The harvester successfully harvested saskatoons, sea buckthorn and chokecherries at 94%, 76% and 82% efficiency, respectively.

2. Technical Report

2.1 Background

There are many fruit crops on the Canadian Prairies that are quickly increasing as viable alternatives to traditionally grown foods. Fruits that are growing the fastest in popularity are saskatoon berries, sea buckthorn berries, and chokecherries.

Saskatoon berries are produced by the woody saskatoon brush (*Amelanchier alinfolia*). These plants typically grow to 2.5 meters in height but can easily reach 5 meters in the wild. The typical berry harvest, which often begins in mid to late July, can produce in excess of five pounds of large, dark blue berries per tree. These hardy bushes are native to the northern climates of North America, and have been used for their nutritional value for centuries by both Natives and early settlers ("Saskatoon Production in Manitoba", 2001).

Chokecherry shrubs (*Prunus virginiana*), are also native to North America, and can be found from New Mexico to the Yukon in both wild settings, and as part of shelterbelts here on the Canadian Prairies. Like the saskatoon bush, chokecherry shrubs can grow to heights of 5 meters and over, but are typically found in orchards at 2.5 meters and below. They produce a small-pitted fruit that had historically been used as a source of food and is growing in popularity once again ("Chokecherry Production in Manitoba", 2001). The crop is typically ready to harvest in mid August to early September, after the saskatoon harvest is complete.

Sea buckthorn shrubs (*Hippophae rhamnoides* L.) are the source of sea buckthorn berries. These hardy, thorny plants can grow to heights of 2 to 4 meters, and thrive in northern climates. For centuries the berries have been used outside of North America for their medicinal and high nutritional values, and in this century the tree was brought to North America and has found a use in shelterbelts on the Canadian Prairies. Sea buckthorn berries are more difficult to remove from the trees than typical fruits. However, each tree can supply upwards of 22 pounds of fruit (depending on the cultivar). The harvesting dates for these berries are very flexible, with an open window any time between mid September and January (Schroeder, 1998).

Being able to reliably supply a steady volume of berries for processing opens up possibilities for existing processors to incorporate them into their operations and the establishment of a berry processing industry. Market growth depends upon an ability to meet demand and supply a consistent product.

In response to the favourable outlook for these three fruits, the agricultural industry has seen a drastic increase in the number of acres planted. Unfortunately, for many of the small orchard operations to become profitable and evolve beyond a cottage industry, a simple, inexpensive means of mechanically harvesting these berries has to be found. Currently, there are several machines on the market that, with some minor modification, can harvest saskatoons and chokecherries with some success, but they are expensive ("Saskatoon Production in Manitoba", 2001). PAMI, along with the PFRA, the University of Manitoba and the University of Saskatchewan in a previous project entitled "Mechanical Harvesting of Sea Buckthorn (Hippophae rhamnoides L.) - An Inter-Provincial Study" produced a harvesting device that, through vibration of the tree's limbs, was found to successfully harvest the sea buckthorn berries. It is the goal of this current project to continue modifications to this harvester to allow it to harvest saskatoons and chokecherries. It is also a goal to produce a collection system that would complement the harvester design, to gather the berries that have been harvested.

2.2 Objectives

The main objectives of the project are:

1. Design, fabricate and evaluate a berry collection system for the sea buckthorn harvester
2. Design, fabricate and evaluate an automated clamping system for the sea buckthorn harvester
3. Investigate the effectiveness of the sea buckthorn berry harvester for removing saskatoons and chokecherries.

2.3 Project Activities – Year 1

2.3.1 Design and Fabrication

The Prototype Harvester

The original trailer-mounted harvester unit was replaced for a number of reasons, primarily its lack of manoeuvrability. The trailer's width of 2.6 metres (102 inches) made it impractical in 3-4 metre (9-12 feet) row spacing, as recommended in the orchard. The dampening of the shaking action by the trailer suspension as well as the impracticality of tying up a trailer for the summer and fall were also drawbacks. A convincing reason to redesign came with the realization that the manufacturer of the custom-built, hydraulic, linear actuator purchased for the original harvester would no longer provide support. These factors led to the decision to develop a commercially viable harvester, deviating from the proposal of modifying the existing setup. A John Deere industrial compact excavator was selected for its high hydraulic flow rate of 33.6 litres per minute (8.9

gallons per minute) compared to its power rating of 9.2 kilowatts at 2300 revolutions per minute (12.3 horsepower). A hydraulically controlled A-frame or scissor style arm was designed and manufactured at PAMI. **Figure 1** shows the compact excavator and the arm. A stock hydraulic cylinder having a 1-inch stroke was used to provide the shaking action. A solenoid valve and PLC controller that allowed the operator to select different shaking frequencies activated the cylinder. After the saskatoon harvest trial, the solenoid was replaced with a servo valve to provide increased shake frequency. This modification also necessitated the addition of a hydraulic oil filter. The design criteria and component selection focused on providing an economical unit. Stock or readily available components were specified as often as possible.

Figure 1. Compact Excavator, Harvesting Arm and Collector

The Clamping System

After considering the different physiological characteristics of the target trees, a claw was developed to handle branches from 13 millimetres to 38 millimetres (½ inch to 1½ inches) in diameter. Two cantilevered hands with interlocking fingers were mounted to a hydraulic cylinder. A block in the back of the cylinder was screwed onto the shaft of the cylinder and connected to the hands with a pin. Retracting the shaft pulled the block back and closed the claw. The cylinder was activated from the operator's platform, eliminating the need for manual clamping, as shown in **Figure 2**. Rubber matting was glued to the inside of the claw to lessen bark damage. This entire assembly was threaded onto the shaker cylinder. Mounted on the back of the shaker cylinder was a rack and pinion to provide a rotational movement, or wrist action, to grab branches. The rack was operated by a hydraulic cylinder activated from the operator's platform.

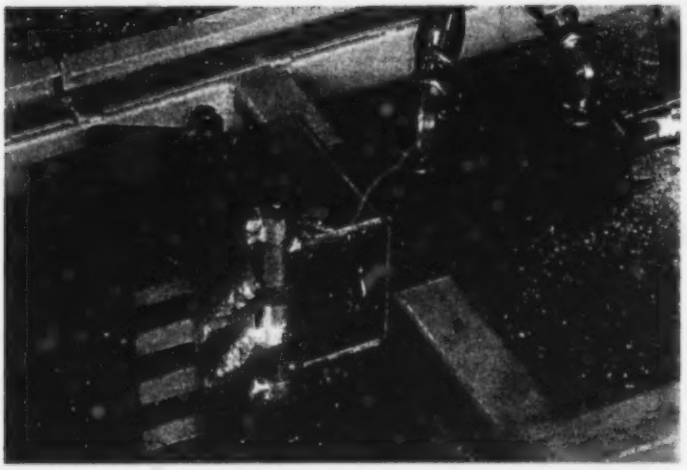

Figure 2. Claw and Cylinder

The Collection System

The collection system, as seen in **Figure 3**, was essentially a large plate 81 inches long and 64 inches wide with a 41 inch tapered slot measuring 9 inches at the mouth and 6 inches at the end, in the middle for the tree trunk. It was attached to the excavator by the blade mounts and raised and lowered by the hydraulic cylinder on the unit. The collection area was composed of plywood mounted to a metal frame. The excavator had to be manoeuvred so the slot lined up with the shrub to be harvested. The excavator was then driven forward to properly position the collector around the base of the shrub.

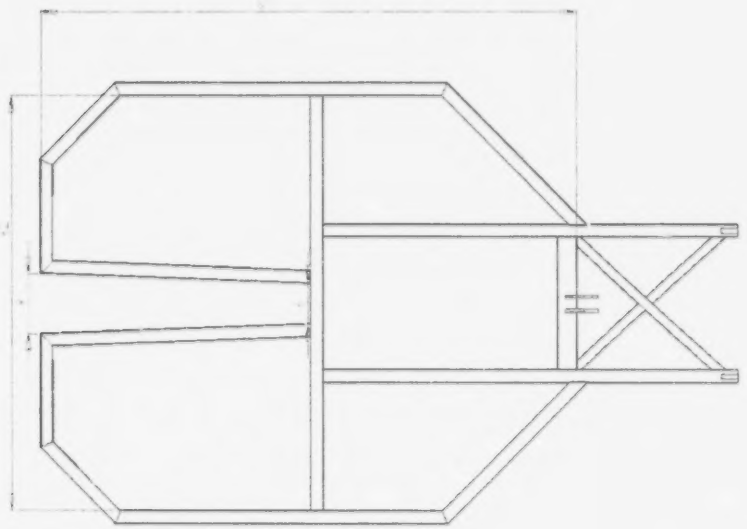

Figure 3. Year 1 Collection System

2.3.2 Field Testing Methods and Procedures

The test parameters were defined to collect data that would give an evaluation of the efficiency of the machine. The harvester was manoeuvred into position with the collection plate around the base of the tree, and tarps were placed on the ground outside of the area covered by the collector plate. Each branch was shook until all of the berries were harvested to a maximum of 90 seconds. After the harvest interval, the berries were collected from the tarp, collector and tree. Each individual sample was bagged and labelled separately as to their collection point, then stored in a cooler and transported back to the Portage la Prairie office where they were weighed and compared. Branch diameter was measured and recorded, as was bark, branch and tree damage. Accelerometer data was recorded on three trials in each test fruit in an attempt to determine relative displacement between the tree and claw. Berry quality was not measured for this harvest period but field observations were recorded for reference purposes.

2.3.3 Results and Observations

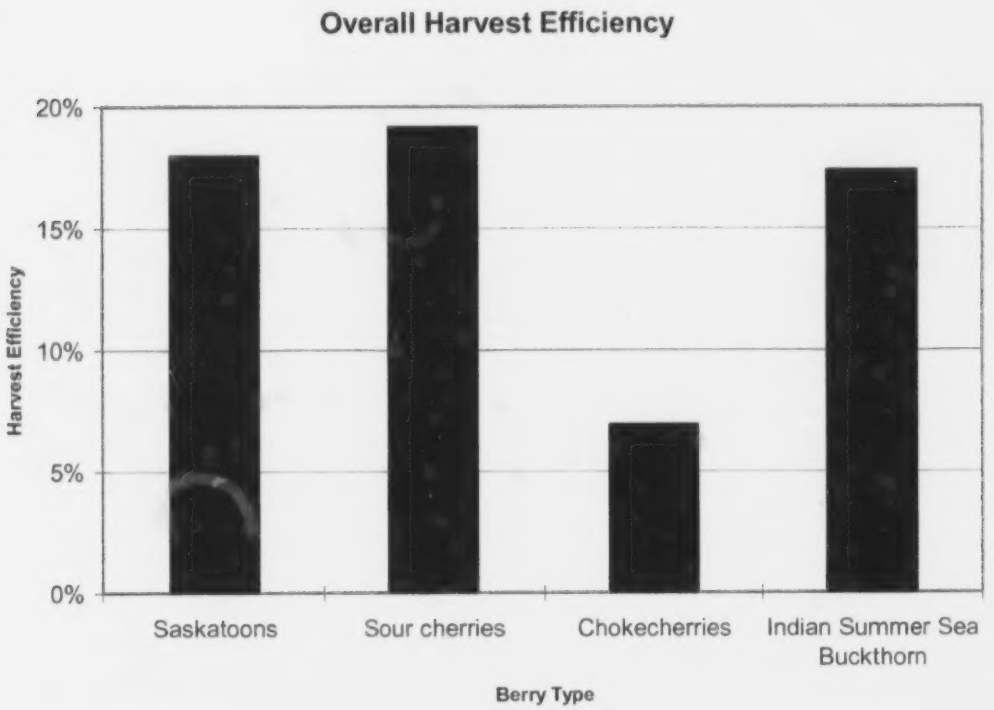

Figure 4. Year 1 Harvest Results

Overall harvester efficiency for the first harvest year is presented in **Figure 4**. **Figure 5** shows the berries collected as a percentage of the berries harvested. Tabular data is too large to be presented and is available electronically in an Excel spreadsheet. Both the saskatoon and sour cherry trials exhibited an average harvest efficiency of just under 20%. The collector was not used on the saskatoons and collected 76% of the sour cherries harvested. A considerable number of cherries were observed bouncing or rolling off of the collector. The average Indian summer sea buckthorn harvest rate is just under 15% with the collector catching 66% of the harvest. Eight trials were performed on the Sinensus sea buckthorn and the harvest rate was estimated at less than 5%. Data was not collected for these trials.

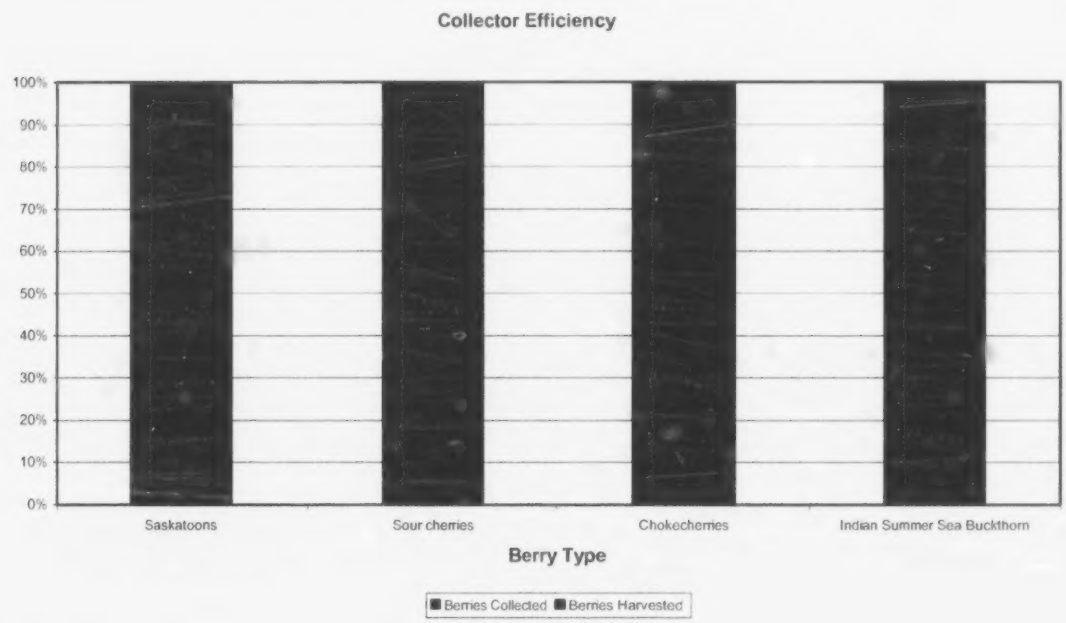

Figure 5. Year 1 Collector Efficiency

The overall average berry size did not appear to differ significantly between harvested berries and berries remaining on the tree branches as shown in **Figure 6.**

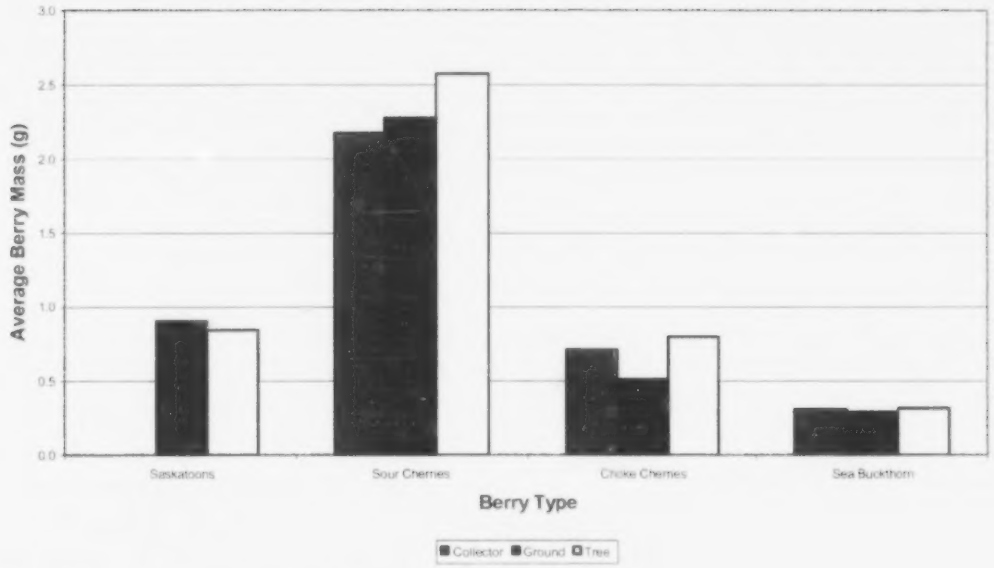

Figure 6. Year 1 Average Berry Mass and Collection Point

Branch size did not appear to affect the efficiency of the harvester. **Figure 7** shows the Indian summer sea buckthorn harvest trials in order of branch diameter. The harvest efficiency does not show any evident pattern.

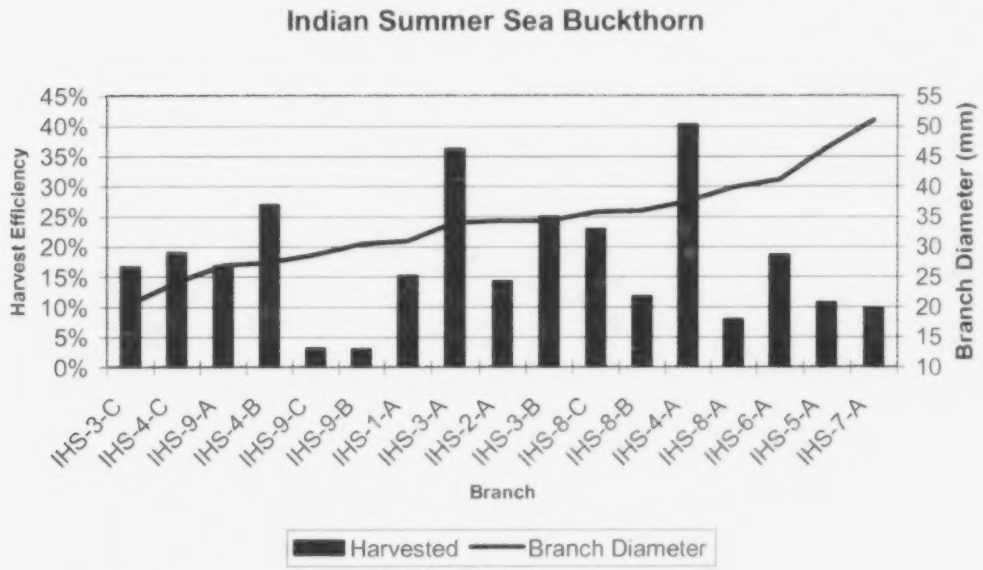

Figure 7. Year 1 Berry Harvest vs. Branch Diameter

Accelerometer data analysis showed good cohesion between the tree and the claw at the tested frequencies. The frequency measured at the claw corresponded with the frequency set on the machine's PLC. Displacement was calculated at 17 millimetres or 0.68 inches at 12 Hz.

Tree damage observed was caused by many different factors, all attributed to operator error. Most noticeable damage came while trying to align the claw to the tree branch. The outside of the claw did considerable damage to nearby branches. Running the claw into the target branch caused minor damage. The only damage during shaking occurred when the claw was not properly aligned. The branch had to be firmly against the back of the claw or the claw would not close tightly causing shear damage to the bark. If more force was applied to the claw action by increasing the pressure in the cylinder, bruising occurred on the trees and the claw fatigued prematurely as shown in **Figure 8**. The cylinder that controlled the wrist action had a tendency to return to the neutral position during the shake process. This did not present a significant problem. The shaking process generated a significant amount of heat in the shaking cylinder and connecting hoses. This did not affect the tests, as there was ample time to cool the cylinder while the samples were gathered between trials.

Figure 8. Damage to Claw from Excessive Clamp Force

Overall performance did not meet expectations. Considerable amount of time was spent aligning the claw to the target branch, which was not desirable in the suckering fruit crops such as saskatoons. The height difference between the operator and the claw and the heavy foliage obscuring sightlines made alignment difficult. Considerable wear of the rack and pinion was observed and the rack had to be replaced.

2.4 Project Activities – Year 2

2.4.1 Modifications

The prototype harvester

In May, the stroke of the shaker cylinder was measured in the lab using a Linear Variable Displacement Transducer (LVDT) to verify the displacement at several shake frequencies. A hydraulic flow meter was also attached to measure the oil flow at the shaker cylinder. The displacement dropped as the frequency increased, from a full 1 inch at 10 Hz to ½ inch at 24 Hz. The flow remained constant at 6 US gallons per minute (USGPM). For economic considerations, the cylinder had to be modified to meet performance requirements. By increasing the shaft size and, in turn, reducing the surface area of the piston in the cylinder, the oil flow requirements of the system would be reduced. A 1¼ inch diameter shaft was fitted to the 1½ inch piston to achieve a more desirable piston surface area. A custom shaft and cylinder end blocks were machined to make this arrangement work. **Figure 9** give us a cross section of the custom machined cylinder and shaft. Subsequent field-testing would prove this cylinder more successful than the previous setup.

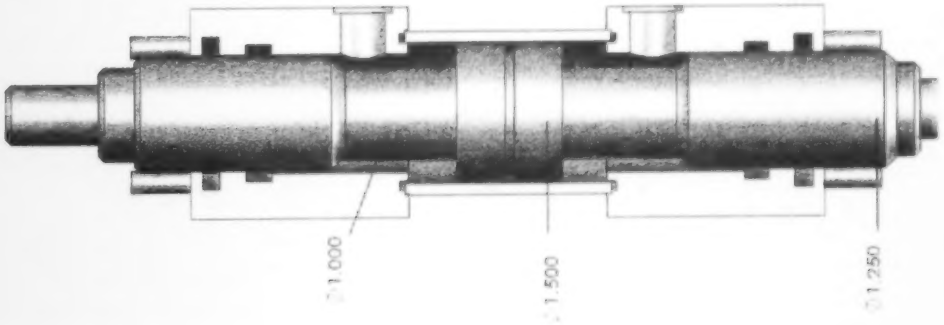

Figure 9. Shaker Cylinder Cross Section

The Clamping system

The rigidity of the rack cylinder mount was increased, which allowed the proper clearance to be maintained between the rack and pinion. Significantly less wear on the

rack and pinion were noticed without losing any performance or range of motion. The cylinder moving the rack back and forth was mounted to the shaker cylinder support bracket as in **Figure 10**, instead of the back of the shaker cylinder itself as in **Figure 11**.

Figure 10. Year 2 Rack Cylinder Mount

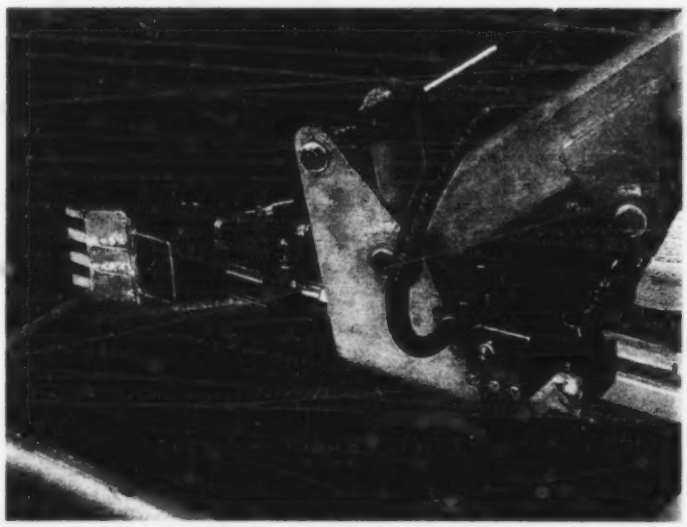

Figure 11. Year 1 Rack Cylinder Mount

The Collection System

The collector built in Year 1 proved to be unwieldy in an orchard setting. Constantly driving and turning into the row of trees proved inefficient and occasionally, due to the length of the collector and harvester, was unable to manoeuvre between rows in this manner. The collector system was redesigned to extend from the side of the unit,

leaving the tracks parallel to the row of trees as shown in **Figure 12**. Consequently, the harvester was able to drive straight up and down the orchard rows without turning. Originally, the idea was to suspend the collector from the swing housing. In theory, both rows on either side of the harvester could be harvested in one pass. This would be economical and should be considered for a production version. The main drawback was the height. This would have made the collector too high to fit under some of the low-lying branches. It would also be beneficial for our purposes to have the collector and arm move independently of one another when collecting the harvested berries during testing. The shaker arm could be swung out of the way allowing clearer access to the collector as it surrounded the tree. The collector was eventually mounted on the under carriage. A piece of ¼ inch steel plate was bolted to the undercarriage and extended just over the tracks. A piece of 2 inch x 4 inch square tubing was welded to the steel plate aligned parallel with the tracks. Bolted to each end of the tubing were brackets with roller supports that held two pieces of 1½ inch x 1½ inch square tubing with pneumatic castors on the ends. They were able to slide in and out of the brackets allowing the collector to extend into the tree line for harvesting and collapse for transport between trees. Mesh was suspended between the two lengths of tubing. Extending from the end of the each piece of square tubing is a piece of ⅜ inch rod bent into a semi-circle. Mesh was suspended from the rod also. A slot for the tree was created by the space between the semi-circles. The collection medium chosen was a mesh window screen. This was more yielding to the berries, causing less damage, than the previous collector and it allowed the collector to retract for transport between harvest setups as shown in **Figure 13.**

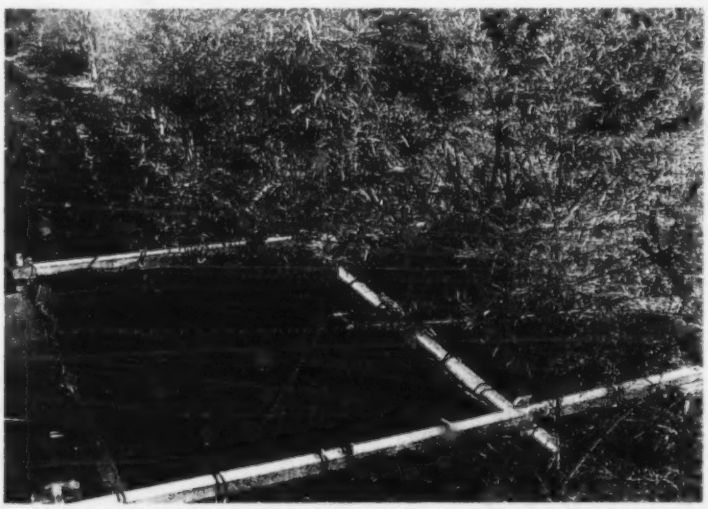

Figure 12. Year 2 Collector System

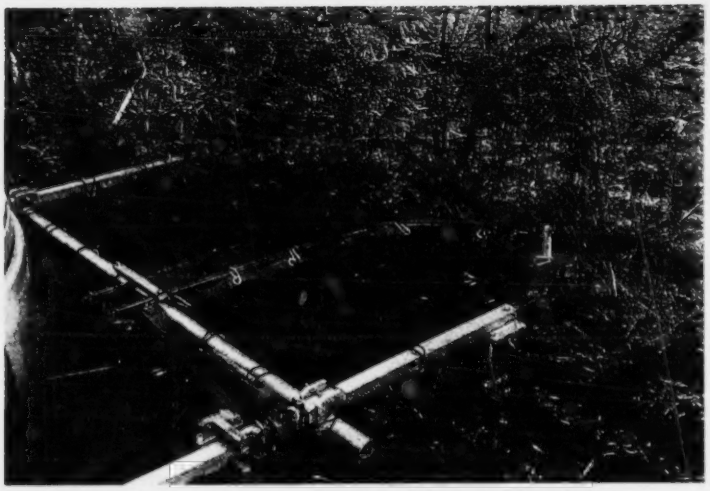

Figure 13. Collector System Retracted for manoeuvring

2.4.2 Field Testing Methods and Procedures

The same methodology and procedures as year 1 were followed with one exception. Accelerometer data was only collected on the Sinensus field trials.

2.4.3 Results and Observations

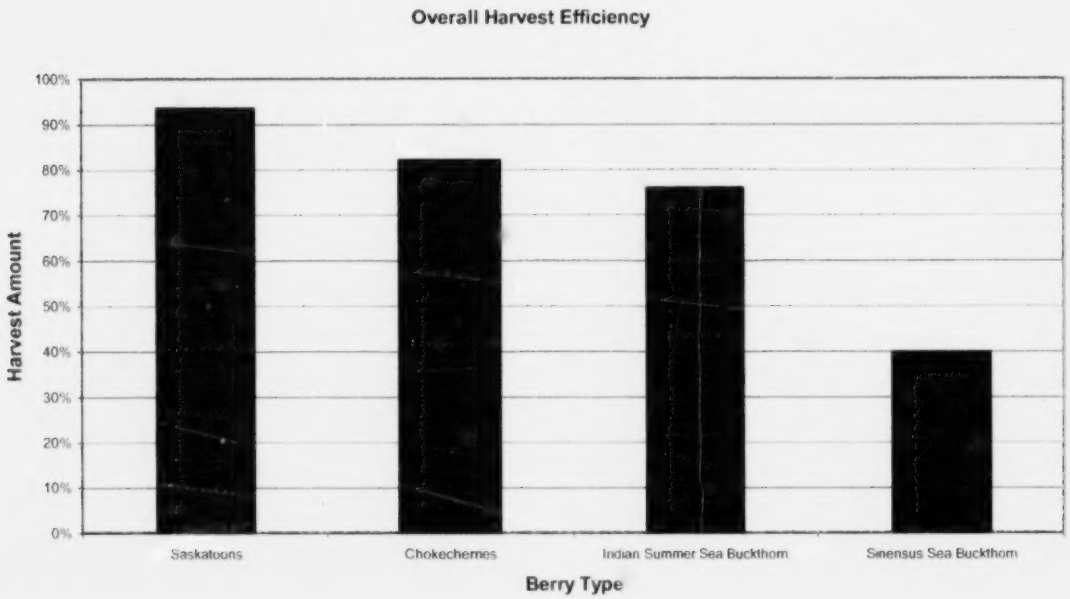

Figure 14. Year 2 Harvest Results

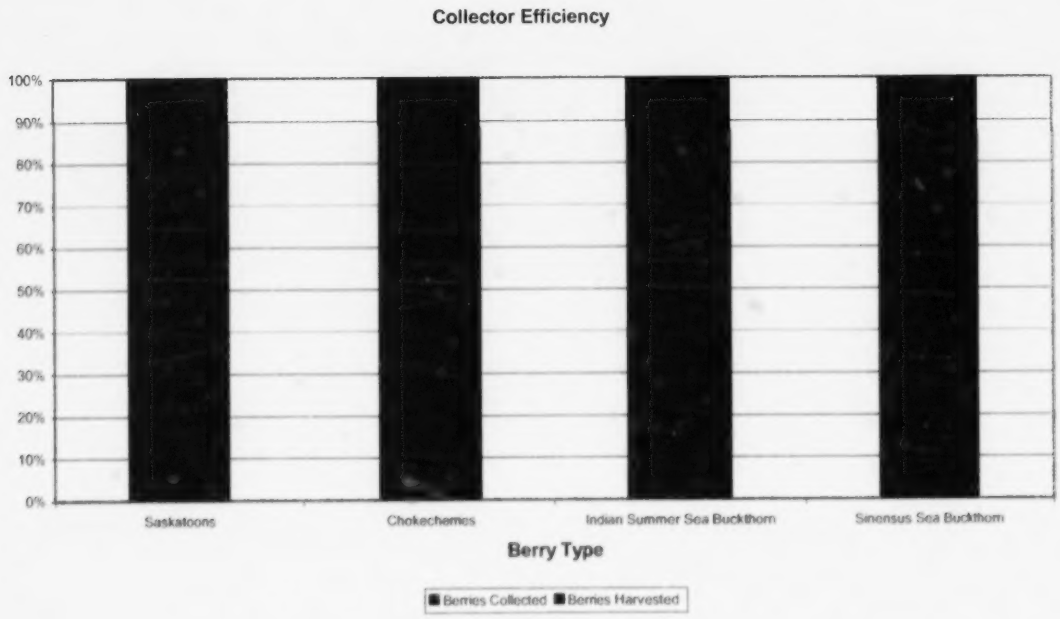

Figure 15. Year 2 Collector Efficiency

The overall harvest efficiency averages are shown in **Figure 14** and the collector efficiency expressed as a percentage of berries harvested are shown in **Figure 15.** They are considerably higher than year 1 and closer to expectations. Again, tabular data is available in an Excel spreadsheet. The saskatoon harvest was very successful with a 94% harvest rate. The collector did not fit the saskatoon shrubs and therefore was not used. 82% of the chokecherries were harvested but only 49% were collected. The low collection rate is due to the fact that the collector could not extend into the tree line because of the suckering nature of the chokecherries. Indian summer sea buckthorn trials resulted in a 76% harvest rate and 56% collection efficiency. The tests were performed on a multitude of varieties at the PFRA Shelterbelt orchard in Indian Head, Saskatchewan. The space between the rows was well groomed, but the sea buckthorn was allowed to sucker in the row. Therefore, only the collector was used in its collapsed state, covering only half of its design collection area. The Sinensus sea buckthorn proved to be a challenge with a 40% harvest rate. The collector worked best with the Sinensus orchard, with 70% of the harvested fruit collected. Individual trial results for Indian summer and Sinensus are displayed in **Figures 16** and **17**, respectively.

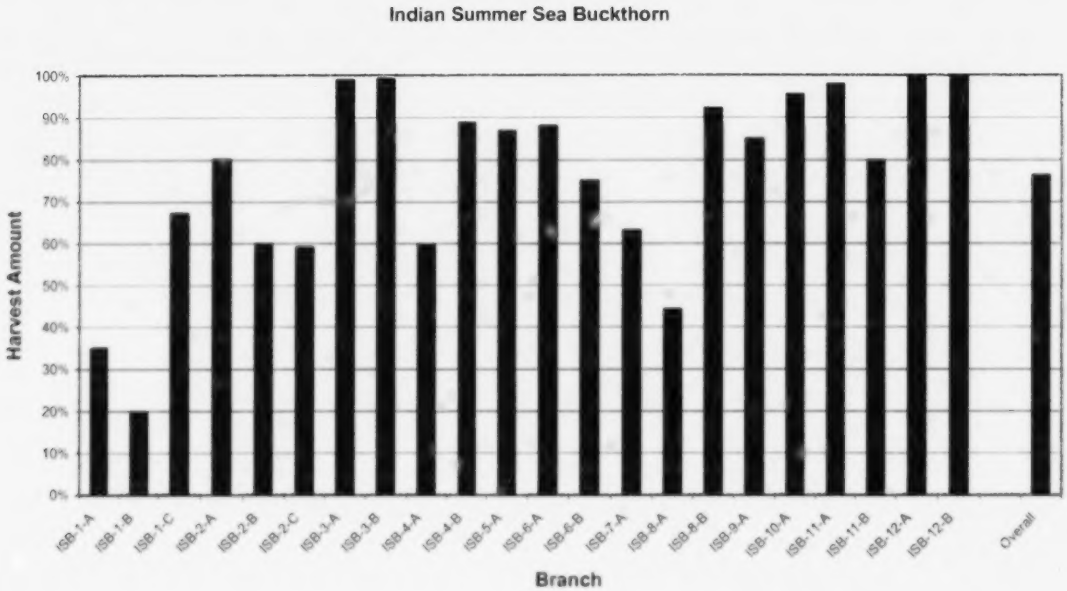

Figure 16. Indian Summer Sea Buckthorn Harvest Results

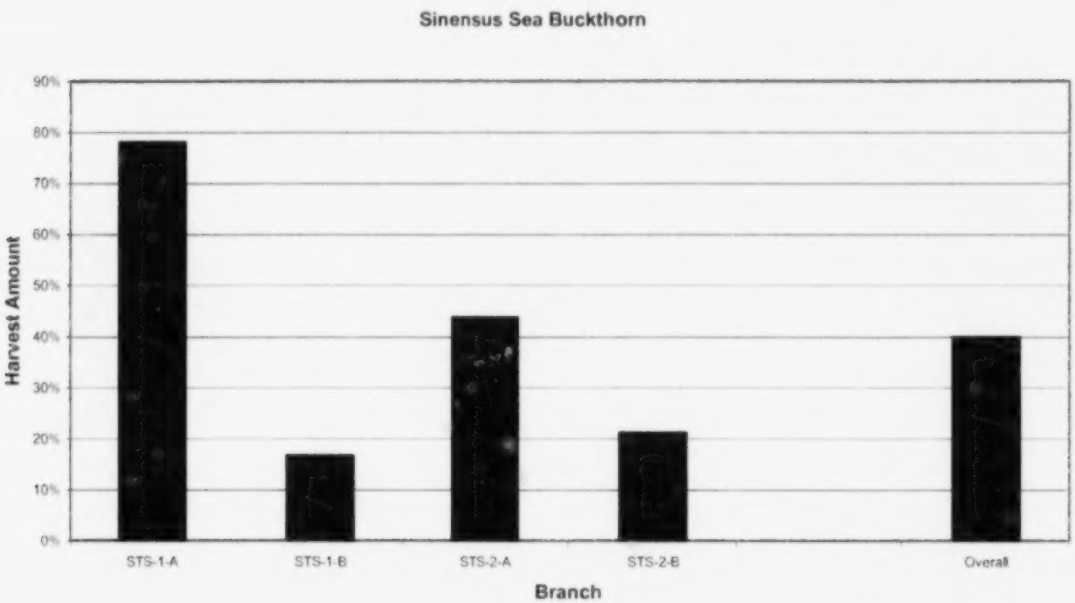

Figure 17. Sinensus Sea Buckthorn Harvest Results

Again, analysis of the accelerometer data showed the frequency measured at the claw corresponded with the frequency set on the PLC. Displacement was calculated at 24.8 millimetres or 0.98 inches at 19 Hz and 25.4 millimetres or 1.00 inch at 22 Hz.

Considerably more debris in the form of leaves was collected in year 2. The chokecherry trials were the worst, by visual observation, for leaf removal and Sinensus sea buckthorn had considerably more small branch removal as shown in **Figure 18** and **Figure 19**. The smaller branches at the top of the tree were more susceptible to damage. The shaking action seemed particularly violent at 19 Hz and did the most damage to the trees. Otherwise bark damage from the clamping system remained the same as in year 1, predominantly caused by the operator.

All the modifications contributed to a more successful harvest. Although the berries were harvested successfully, the time to align the claw to the branch continues to be a concern, especially on fruits and berries that are easily hand picked.

Figure 18. Sinensus Branch Damage

Figure 19. Broken Branches

The collector did not perform well in the suckering row fruits. Extensive grooming and maintenance would be required. Using only half the collector and extending it to the tree line worked well at the PFRA sea buckthorn orchard. Areas between the rows were well maintained but the plants were allowed to sucker in the rows. The collector did not appear to damage the berries or trees if properly deployed. Berries harvested under optimum conditions were not observed to be noticeably soft, bruised or burst while gathering from the collector. Berries were not observed to bounce or roll off the collector.

2.5 Conclusions and Discussions

The overall performance of the harvester and collector met expectations in all fruit crops except the Sinensus variety of sea buckthorn. A reasonable expectation for harvest efficiency in a traditional agricultural crop in Western Canada is 95% and up. Comparing this to a 40% harvest rate is quite discouraging. Is this a reasonable expectation for a sea buckthorn harvester? Compared to available harvest technology, the PAMI built harvester is more than acceptable. The only available sea buckthorn harvester is a German model that has an efficiency rating of 25-35% on a whole orchard harvest. The price is 150,000 euros and the manpower requirement is 6-9 people. It is more like a traditional threshing machine and uses a pruning method to input raw material, a vibrating cylinder to remove the berries, an air cleaner to clean the berry sample and discharges the branches out the back of the machine. Typical German orchards harvested in this method have a production life of 10-15 years, considerably less than the 25-year production life of the shrub.

The variation in physical and biological properties between trees is apparent when the fruit is compared. Different sizes, shapes and colours of berries are evident in a single orchard. This leads to large differences in harvest rates between trees in an orchard.

Considerable more branch damage was observed during the shaking process in Year 2. The improved performance of the shaker cylinder may have resulted in a more aggressive harvest process, the extended period of near drought conditions could have made the branches more brittle or the shake interval could have been too long. Most likely it is a combination of these factors. Aligning the claw to the target branch was very time consuming. Proper positioning of the branch in the claw was required to ensure minimal bark damage during harvesting. The A-frame arm design was inadequate in this regard because extending the claw outwards was not done in a linear fashion. Considerable practice was required to align the claw smoothly and efficiently.

Considerable movement of the A-frame arm was observed during the shaking process and, although it was not reflected negatively in the accelerometer data, was a cause of concern. Excessive fatigue of the joints could lead to premature failure.

The collector performed as expected in the well-groomed orchard and proved to be somewhat adaptable. The collector is designed to fit in a production orchard following the plant spacing recommendations outlined in the Sea Buckthorn Growers Guide. The test orchard for Sinensus was the only production orchard tested in and the collector fit extremely well. The producer had laid the poly down which prevented the suckers and had put considerable effort into grooming the orchard. Collector performance is, therefore, directly related to the attention paid to grooming the orchard. By leaving the collector retracted, the operator would be able to harvest branches on trees where the collector did not fit and still expect reasonable performance, especially on branches leaning towards the collector. The improved performance of the shaker cylinder did not require a larger collection area. The mesh did not appear to cause any appreciable damage due to impact. It was also not affected by wind as a canvas tarp may be.

2.5.1 Recommended Future Development

There are several key areas which future research should address. Improving the rigidity of the arm would be key. This may mean returning to a telescoping style from the previous research or by simply having a better alignment of the hydraulic positioning cylinders. Secondly, the development of a self-aligning claw would speed up the harvest process considerably. The durability of the system should be tested. The limited number of trials performed is not analogous to a full season of harvesting.

The collector from year 2 was manually extended and retracted. Automation of this feature to allow it to be activated from the operator's platform would be desirable. The current design lends itself to hydraulic or electric actuators. This project only focused on the collection of the harvest at the tree base. A method of transporting the harvested sample from the collector to storage and removing debris is required to complete the system.

Further work could be done on the adaptation of the harvester to other fruit crops. Attachments instead of the claw could be developed to harvest multiple branches or develop fingers to turn it into a foliage shaker to harvest the suckering hedgerow crops such as saskatoons and chokecherries. Conversely market studies could be done to determine the viability of orchards groomed to accept the harvesting system in its current form. Sour cherries are the most promising of the additional crops tested. They grow similar to sea buckthorn in size, orientation and orchard style. A testing program in

conjunction with the University of Saskatchewan's breeding program would help select an easily harvestable variety of sour cherry.

Lastly, a long-term research study into the affects of repeated harvesting by shaking on the longevity and performance of production orchards should be considered.

3. Project Timetable

Table 1. Project Timeline

Date	Project Goal	Current Status
October 2001	Start conceptual design of berry collection system (completed by U of M engineering students) Start comparison of sea buckthorn berry, saskatoon and chokecherry plant structure	Complete
December 2001	Complete U of M conceptual berry collector	Complete
January 2002	Start design and fabrication of "claws" for saskatoon and chokecherry plant structure. Start design and fabrication of berry collection system	Complete Complete
February 2002	Finish comparison of sea buckthorn, saskatoons and chokecherry plant structure.	Complete
March 2002	Finish design of "claw"	Complete
April 2002	Finish design of collection system	Complete
May 2002	Finish fabrication of "claw" and collection system	Complete
July 2002	Start evaluation of "claws" Start evaluation of harvester in chokecherries, saskatoons and sea buckthorn shrubs. Start evaluation of berry collection system	Complete
October 2002	Finish evaluation of "claws" Start field data analysis	Complete
January 2003	Finish evaluation of collection system Start modification to "claws" and/or berry collection system	Complete
June 2003	Finish modifications to "claw" and/or collection system	Complete
July 2003	(Formerly May 2003) Start data collection (2nd season) (same as summer 2002)	Complete
October 2003	Finish evaluation of "claws" Start field data analysis	Complete
December 2003	Finish evaluation of collection system	Complete
February 2004	Finish data analysis	Complete
March 2004	Finish final report	Complete
April 2004	Project Complete	Complete

3.1 Presentations and Articles

During 2003, a number of activities have been undertaken to acknowledge the work done towards development of the sea buckthorn crop and to the support received from the Agricultural Development Fund in Saskatchewan and the Manitoba Rural Adaptation Council.

- A presentation of the current sea buckthorn leaf and berry harvester research to the Manitoba Sea Buckthorn Growers Association in Portage La Prairie on December 1, 2001.
- A presentation of the current sea buckthorn leaf and berry harvester research during a workshop at the PFRA station in Indian Head, SK on March 1, 2002.
- A presentation of the sea buckthorn harvester prototype at a Field Day sponsored Manitoba Agriculture at B.B Farms (Bill Linden) in Portage La Prairie on September 7, 2002.
- Article in the Portage la Prairie Daily Graphic
- Discussion for French CBC
- Article for British Columbia Sea Buckthorn Growers Association newsletter
- A presentation of the sea buckthorn harvester at the Manitoba Sea Buckthorn Growers Association Annual General Meeting in Portage la Prairie on Saturday November 22nd, 2002
- Display at Manitoba Ag days in Brandon on January 15th –17th, 2003
- Roger Chagnon, Agriculture and Agri-Food Canada; Lynn Gilmore, Manitoba Agriculture; Gerald Loeppky, Manitoba Crop Diversification Centre; and Charles Roberts, Manitoba Sea Buckthorn Grower's Association, were given an in-house demonstration at PAMI in Portage la Prairie, on February 18, 2003
- Booth at the Direct Farm Marketing Conference in Brandon on February 22nd and 23rd, 2003
- A display at the Western Canada Farm Progress Show in Regina, Saskatchewan on June 17th-19th, 2003.
- A presentation of the sea buckthorn harvester prototype at the Canadian Society For Agricultural Engineers (CSAE) Annual General Meeting in Montreal, Quebec on July 6th – 9th, 2003.
- A presentation of the sea buckthorn harvester prototype at the Canadian Society For Agricultural Engineers (CSAE) Regional Technical Meeting in Winnipeg, Manitoba on November 25th, 2003.

4. References

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